Transformational Space Concepts & Technology Winter 2004 Workshop

- Materials for Future Space Missions -

EVA Material Challenges

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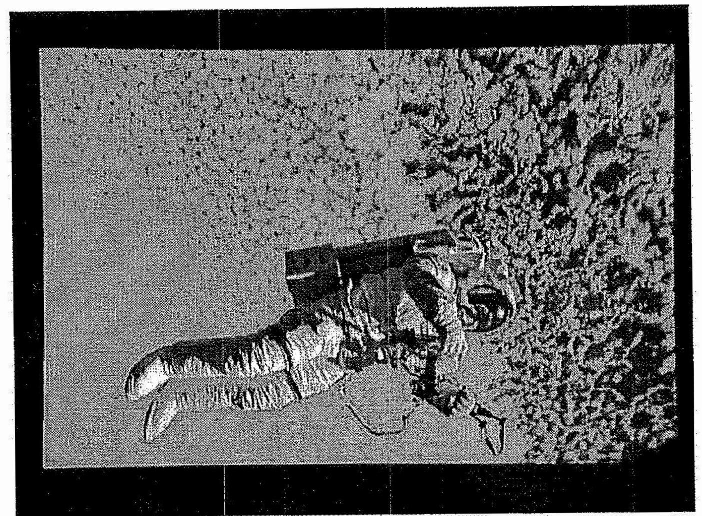
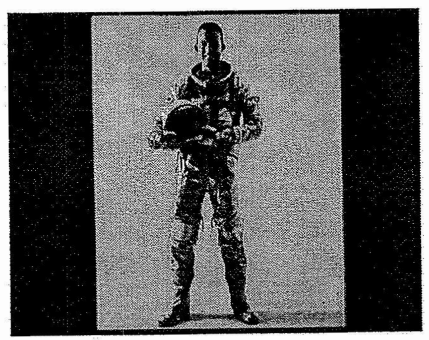
Overview

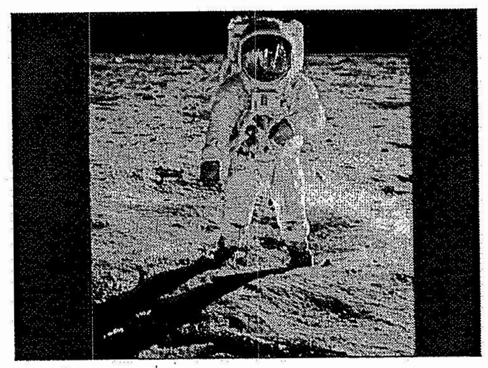
- Historical Perspective on Aerospace Textiles
- Current Shuttle/ISS EMU Fabrics
- Advanced Space Suit Material Challenges

Milestones in Spacesuit Textile Technology

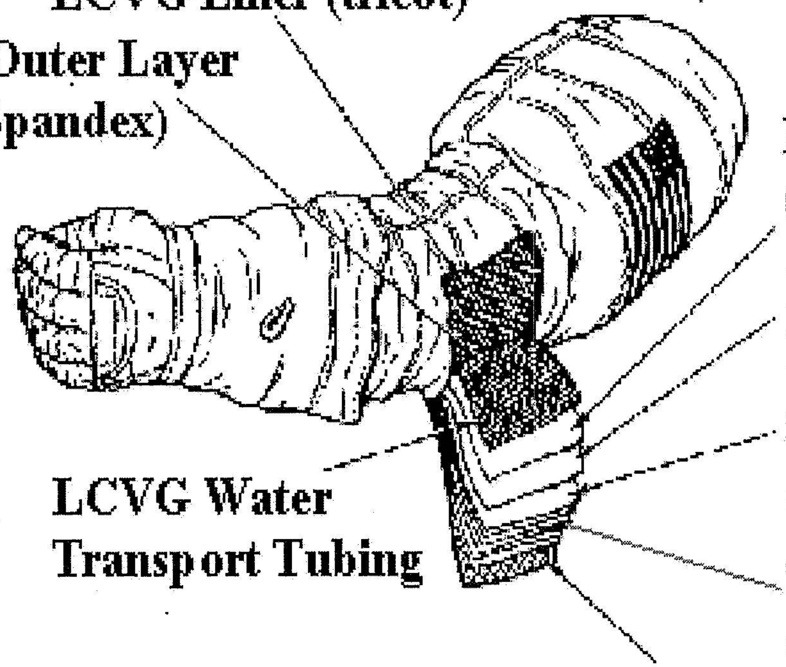
- **1960's (Mercury, Gemini)**
  - Aluminized nylon
  - Neoprene coated nylon
- **1970's (Apollo, Apollo-Skylab)**
  - Beta glass fiber
  - Polybenzimidazole (PBI)
- **1980's (Space Shuttle)**
  - Ortho fabric







Shuttle Suit Fabrics



Why New Materials?

Long duration missions require more robust materials

- Lighter and more durable
- More Effective Insulation (in gas environments)
- Thermally conductive (for thermal regulation)
- Low maintenance (e.g. self healing properties)

Current R & D Activities on Space Suit Materials

- Passive Thermal Insulation Materials
- Conductive Fibers for Inner Thermal Garment (active thermal regulation)

Current Space Suit Thermal Insulation Issues

- Aluminized Mylar Multi-Layers Insulation (MLI) is limited to low Earth orbit (LEO) or high vacuum environment application
- Environment with gas atmosphere will reduce the insulation capability of MLI to unacceptable level
- MLI is prone to tear and not very durable
- Future space suit insulation will require operation in both high vacuum (LEO & Moon) and gaseous environment (Mars)

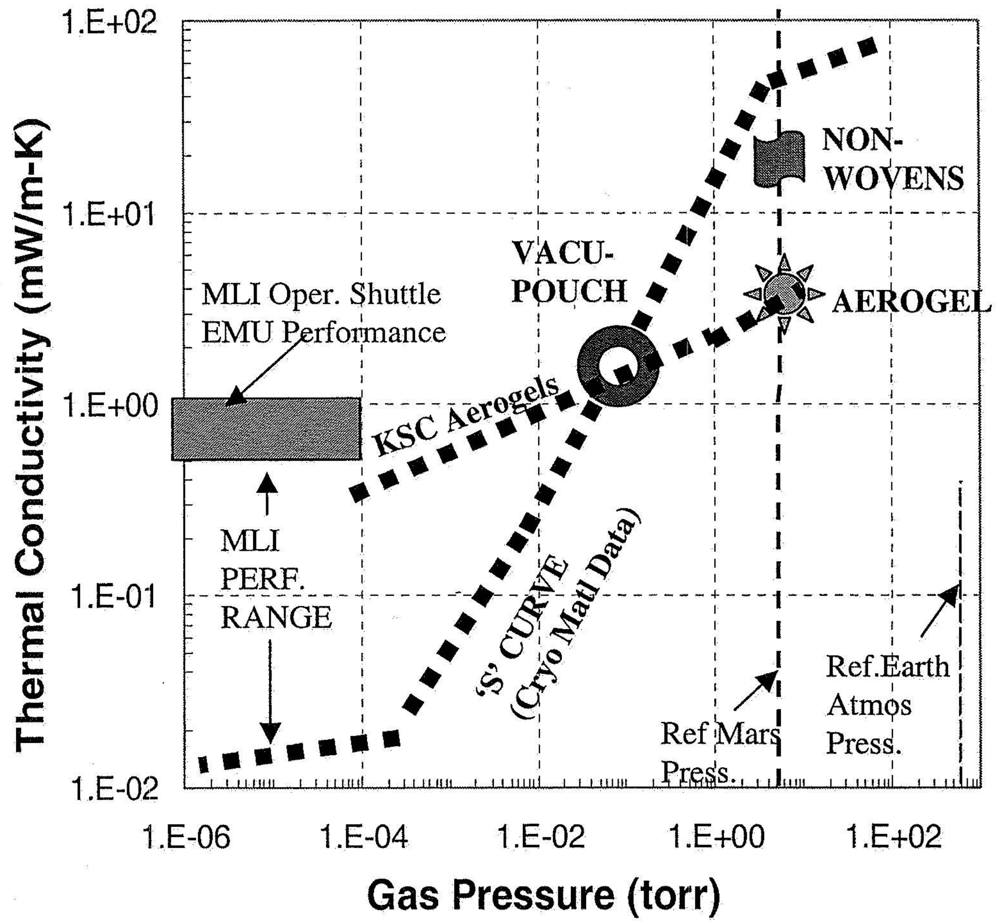
Passive Thermal Insulation

- Four studies were conducted or are in progress:

  - Lofty Fibrous Nonwoven Structures
  - Flexible Silica Aerogel Composites
  - Flexible Vacuum Enclosures
  - Nanofiber Composite Structures

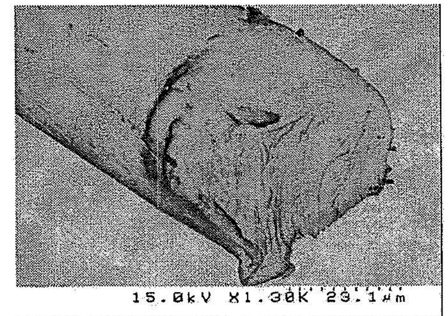
Suit Performance Expectations

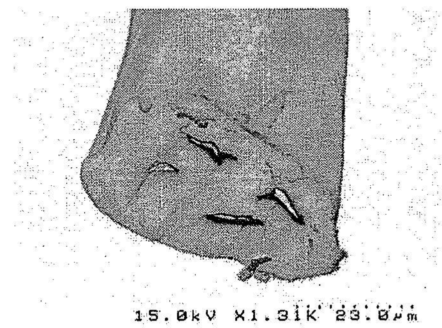
Schematic generated from analytical computation

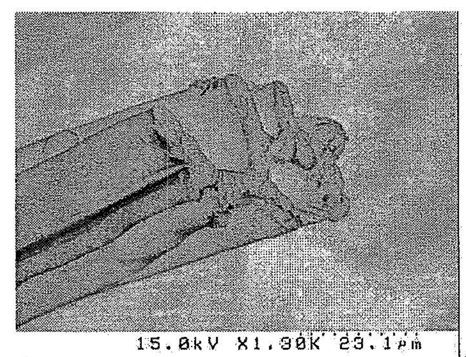


Fibrous Materials as Thermal Insulation and Spacers

- Lofty Nonwovens Features
  - High void/volume ratios
  - Proven effective in 1 g for flexibility
  - lightweight, & thermal performance
- Conclusions
  - Grooved fibers at high vacuum approach MLI performance
  - Traditional fiber is not a solution for Mars environment



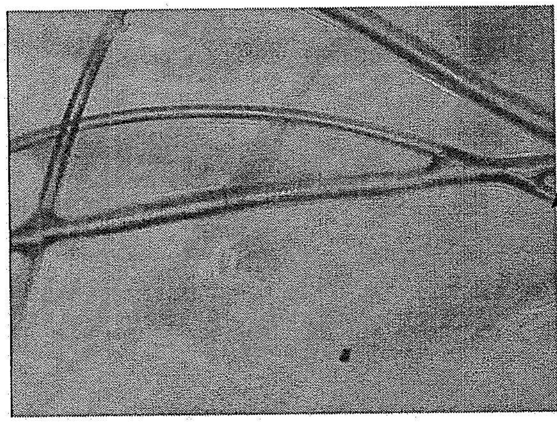




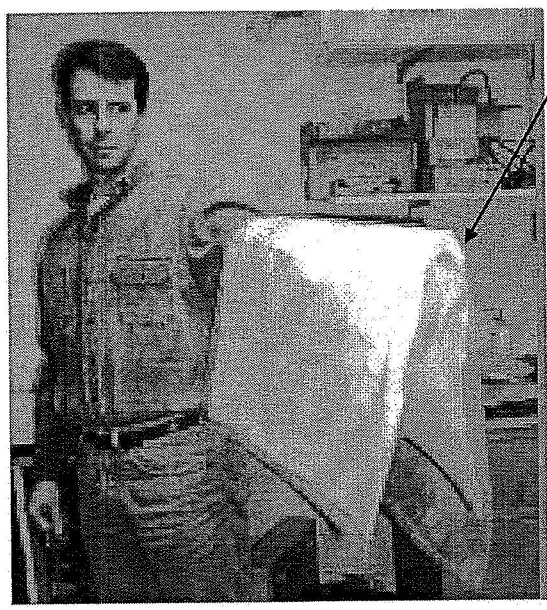
Aerogel Background

- In gas environments, aerogel composite provides 4 to 6 times higher protection than best traditional flexible insulation, including MLI.
- Silica aerogel composite is flexible, but silica matrix is brittle (polymer fibers as reinforcement structure)
- Insulating requirements now met the NASA near Earth missions (bulk requirement of ~13 mm / 0.5 in. or less)
- Durability, flexibility and life cycle properties of silica aerogel composites are currently under investigation
- Non-brittle, rubber aerogel in development

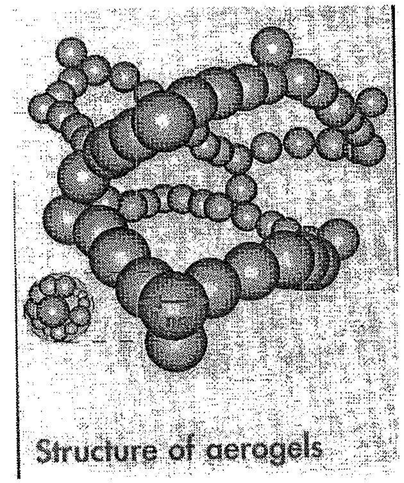
Aerogel Composite Fabric



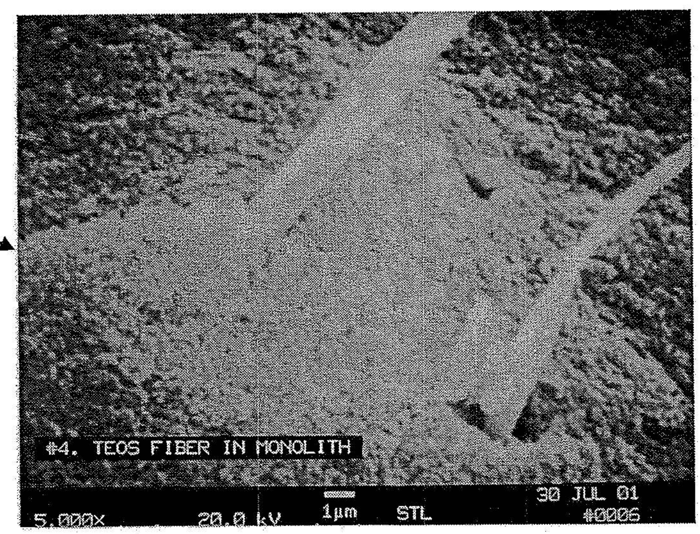
Silica Aerogel / Fiber Interface



Flexibility of Silica Aerogel Composites



SEM of a Silica Aerogel Facture Surface



Comparison Between Aerogel Composites and Other Insulations

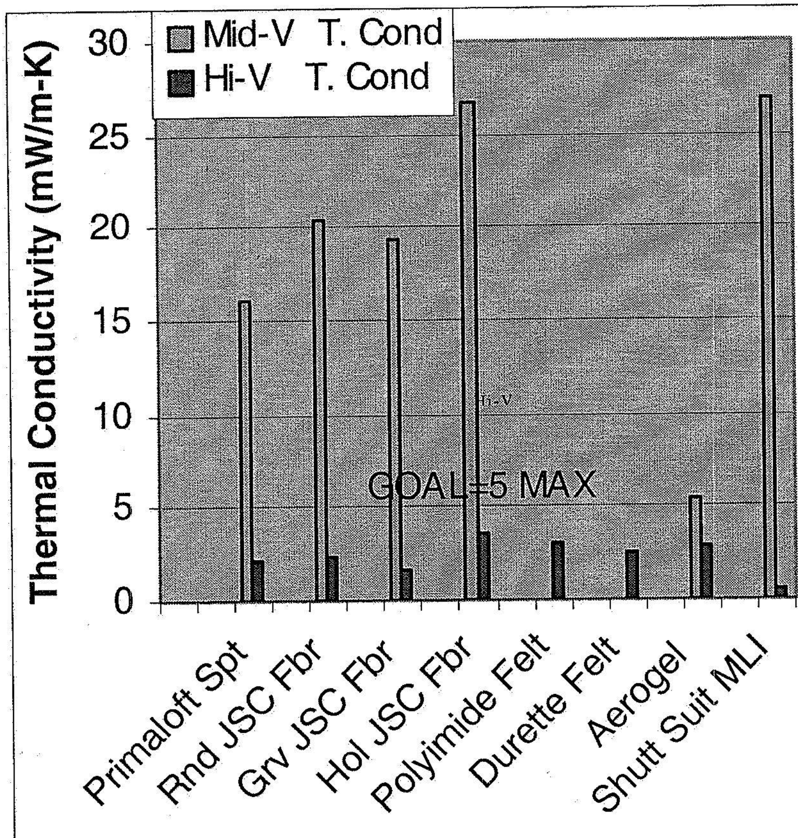


Fig b. Thermal Conductivity

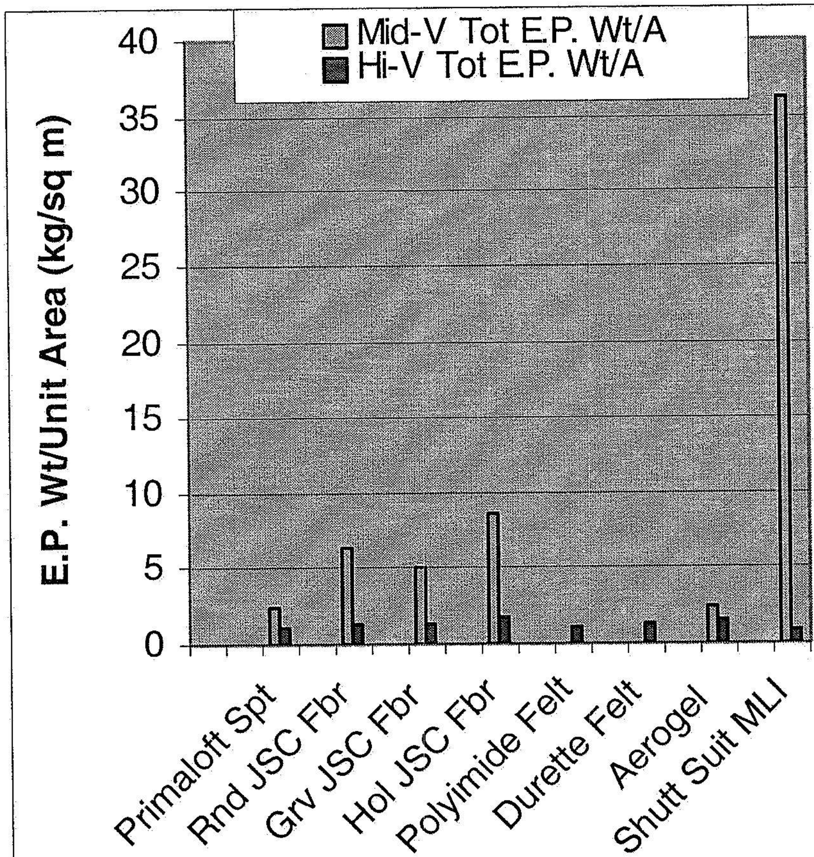
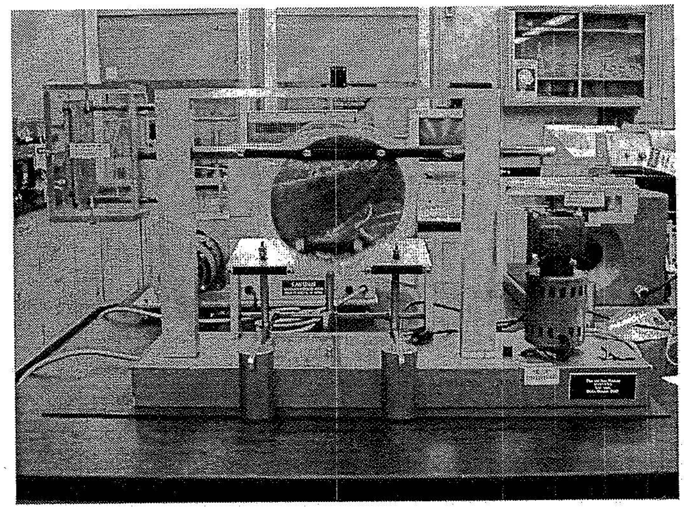


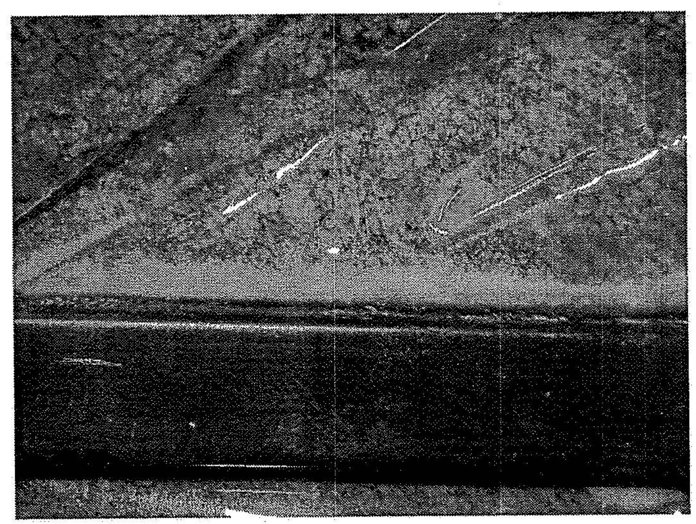
Fig d. E P. Weight/Unit Area

Aerogel Insulation Durability Study

- Effect of mechanical cycling on Aerogel Insulation (Thermal Conductivity) Performance

- The amount of Aerogel breakup and its impact in performance – “Dusting”





Aerogel Insulation Durability Evaluation Preliminary Findings

- **Cycle life goal:** 100,000 cycles on flexible suit elements for extended duration missions.
- **Results:** After 100,000 cycles in a mechanical tester on flat samples, thermal performance for various samples of Silica Aerogel degraded approximately:
  - 23% at 8 Torr (Mars - final k approx 8 mW/m-K)
  - 2.5% at High Vac. (LEO & Moon - final k <5 mW/m-K)
- **Conclusions:** Mechanical tester imposes extreme conditions on samples, but degradation limits are in approx. range of being acceptable. Future tests to be conducted on representative suit element and insulation assembly.

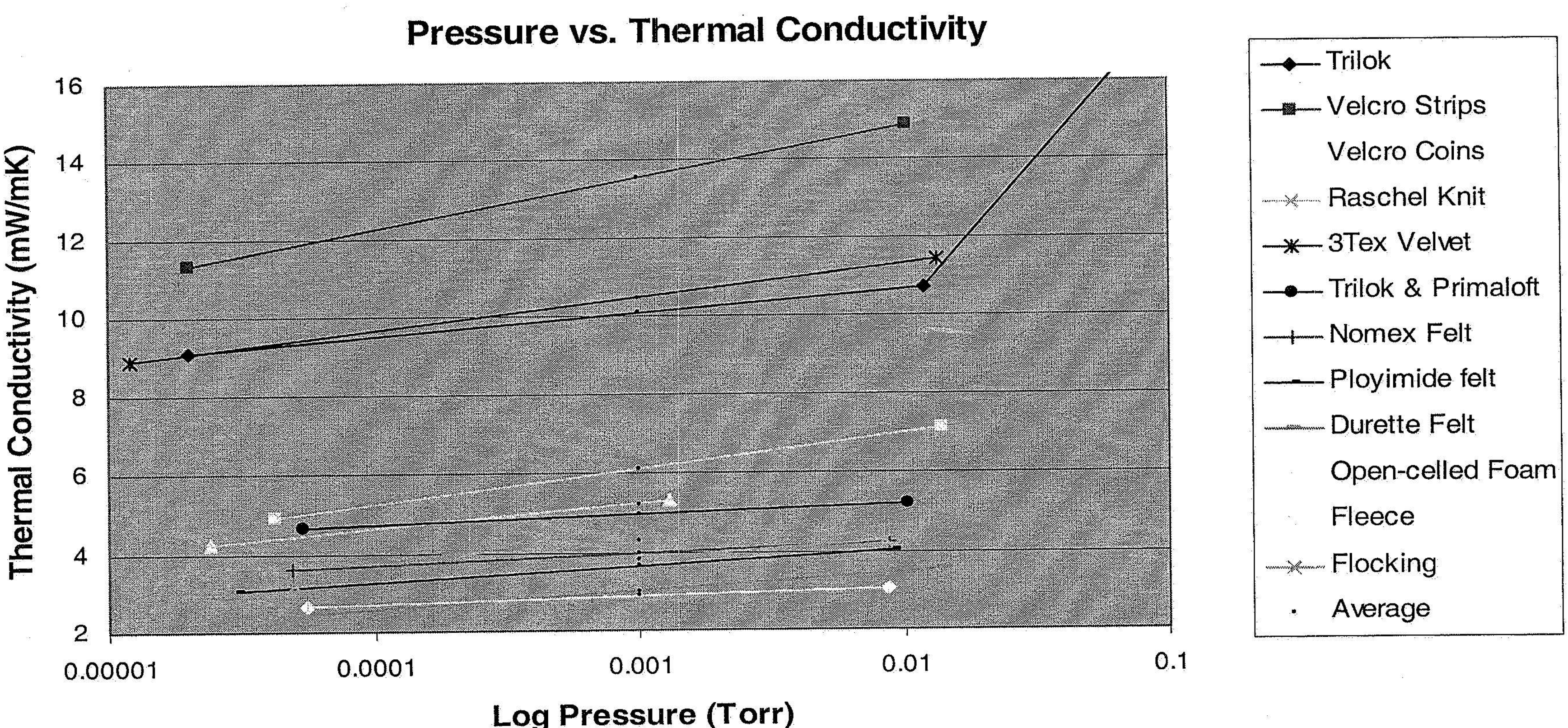
Flexible Vacuum Enclosures

- Concept Derived from Vacuum Panels
  - Open cell polystyrene foam evacuated inside metal foil with an R-value 6 to 8 times that of glass-fiber insulation
  - Used in refrigerator/freezer for Columbus/ISS

- Vacuum Panels Features
  - Lower thermal conductivity at reduced pressure
  - Space suit application difficult because of stiffness, weight, volume, and complexity

THERMAL PERFORMANCE TESTS ON VACUUM ENCLOSURE SPACER MATERIALS

- MAXIMUM THERMAL CONDUCTIVITY GOAL OF 5 mW/m-k WAS ACHIEVABLE AT PRESSURES AS HIGH AS 10-2 TORR.



Nanofiber Structures

- From previous studies:
  - Insulation improves as fiber diameter decreases to critical value ~ 3microns
  - Then at diameters < 3microns, insulation degrades
- Current objective:
  - Test validity of previous conclusions
  - Evaluate fibrous blends with nanofiber components

Thermally Conductive Fiber – Active Thermal Regulation

- Potential Application: Liquid cooling garment for the spacesuit
- First Effort: Development of a highly thermally conductive fiber made of single wall carbon nanotube doped elastomer
- Second Effort: Develop other commercial fibers into new liquid cooling garment with potential to eliminate water loop or reduce its weight.

Conclusion on Advanced Textiles for Spacesuit Applications

- Leading new technology for spacesuit thermal insulation: → **Flexible aerogel composite fabrics**
- Emerging technology for cooling garment: → **Thermally conductive nanotube doped fibers**